CHEMICAL MECHANICAL POLISHING METHOD AND APPARATUS FOR REMOVING MATERIAL FROM A SURFACE OF A WORKPIECE THAT INCLUDES LOW-K MATERIAL

Inventor(s): Tim Dyer, Saket Chadda, Ismail Emesh, and Periya Gopalan

FIELD OF THE INVENTION

The present invention generally relates to polishing a surface of a workpiece. More particularly, the invention relates to improved methods and apparatus for removing material such as low-k material or material deposited over the low-k material using chemical mechanical polishing.

BACKGROUND OF THE INVENTION

Chemical mechanical polishing or planarizing a surface of an object may be desirable for several reasons. For example, chemical mechanical polishing is often used in the formation of microelectronic devices to provide a substantially smooth, planar surface suitable for subsequent fabrication processes such as photoresist coating and pattern definition. Chemical mechanical polishing may also be used to form microelectronic features. For example, a conductive feature such as a metal line or a conductive plug may be formed on a surface of a wafer by forming trenches and vias on the wafer surface, depositing conductive material over the wafer surface and into the trenches and vias, and removing the conductive material on the surface of the wafer using chemical mechanical polishing, leaving the vias and trenches filled with the conductive material.

As the size of microelectronic circuits decreases, the features and the spacing between the features (e.g., interconnect features) generally decreases. This reduction in feature size and spacing may be problematic because a circuit becomes increasingly affected by capacitance coupling between two or more interconnect features separated by a dielectric material as the feature spacing is decreased. Furthermore, as interconnect feature size decreases, the resistance of the feature generally increases (e.g., line resistance increases). As a result, the circuits become increasingly susceptible to crosstalk and to resistance-capacitance ("RC") delays as the capacitance coupling between interconnect features and interconnect line resistance increase.

Generally, the capacitance of two or more conductive features is proportional to the dielectric constant of a material separating the features and inversely proportional to the distance between the features. Consequently, the capacitance coupling of features increases as the distance between the features decreases and as the dielectric constant of material between the features increases. Adverse affects of reduced spacing between interconnect features may therefore be mitigated by interposing material having a low dielectric constant (low-k material) between the interconnect features.

Although low-k material may advantageously affect device or circuit performance, use of such materials may be problematic in several regards. In particular, low-k materials such as porous silica are relatively brittle and thus tend to break up or delaminate during typical chemical mechanical polishing processes. Accordingly, improved chemical mechanical polishing apparatus and methods that reduce an amount of damage imparted to a low-k material on a surface of a workpiece are desired.

SUMMARY OF THE INVENTION

The present invention provides improved methods for chemical mechanical polishing of a surface of a workpiece that overcome many of the shortcomings of the prior art. While the ways in which the present invention addresses the drawbacks of the now-known techniques for chemical mechanical polishing will be described in greater detail hereinbelow, in general, in accordance with various aspects of the present invention, the invention provides chemical mechanical polishing techniques for use with relatively friable materials such as low dielectric constant materials.

In accordance with one embodiment of the present invention, material is removed from a surface of a workpiece by moving the workpiece and a polishing surface relative to each other at a relative velocity of about 0.8 to about 3 meters per second.

In accordance with an exemplary embodiment of the present invention, a polishing process includes moving a polishing surface in an orbital motion with an orbital rotation speed of about 500 to about 2000 orbits per minute. In accordance with one aspect of this embodiment, a down force of pressure of about 0.25 psi. to about 2 psi. is applied to a workpiece in the direction of the polishing surface.

In accordance with another embodiment of the invention, a polishing surface is configured to allow polishing solution to flow through the surface toward a wafer surface and to reduce an amount of friction between the workpiece and the polishing surface. In accordance with one aspect of this embodiment, the polishing surface includes grooves and apertures to direct the polishing solution flow. In accordance with a further aspect of this embodiment, the grooves are configured to facilitate a hydroplaning action, such that the wafer hydroplanes on the polishing solution across the polishing surface.

In accordance with another embodiment of the invention, a temperature control mechanism is provided to regulate the temperature of the polishing solution during a polishing process.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present invention may be derived by referring to the detailed description and claims, considered in connection with the figures, wherein like reference numbers refer to similar elements throughout the figures, and:

Figure 1 illustrates a top cut-away view of a polishing system in accordance with the present invention;

Figure 2 illustrates a side view of a portion of a clean system for use with the apparatus of Figure 1;

Figure 3 illustrates a top cut-away view of a polishing system in accordance with another embodiment of the invention;

Figure 4 illustrates a bottom view of a carrier carousel for use with the apparatus illustrated in Figure 3;

Figure 5 illustrates a cross-sectional view of a polishing apparatus in accordance with one embodiment of the invention;

Figure 6 illustrates a portion of the polishing apparatus of Figure 5 in greater detail;

Figures 7A and &B illustrate a platen including heat exchange channels in accordance with the present invention; and

Figure 8 illustrates a top plan view of a polishing surface, having grooves and apertures, in accordance with the present invention.

Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

The following description is of exemplary embodiments only and is not intended to limit the scope, applicability or configuration of the invention in any way. Rather, the following description provides a convenient illustration for implementing exemplary embodiments of the invention. Various changes to the described embodiments may be made in the function and arrangement of the elements described without departing from the scope of the invention as set forth in the appended claims.

Figure 1 illustrates a top cut-way view of a polishing apparatus 100, suitable for removing friable material such as low-k material and/or material deposited onto the low-k material such as copper or other conductive material, from a surface of a workpiece in accordance with the present invention. Apparatus 100 includes a multi-platen polishing system 102, a clean system 104, and a wafer load and unload station 106. In addition, apparatus 100 includes a cover (not illustrated) that surrounds apparatus 100 to isolate apparatus 100 from the surrounding environment. In accordance with a preferred embodiment of the present invention machine 100 is a Momentum machine available from SpeedFam-Ipec Corporation of Chandler, Arizona. However, machine 100 may be any machine capable of removing material from a workpiece surface.

Although the present invention may be used to remove friable or brittle material or other material deposited thereon from a surface of a variety of workpieces such as magnetic discs, optical discs, and the like, the invention is conveniently described below in connection with removing material from a surface of a wafer. In the context of the present invention, the term "wafer" shall mean semiconductor substrates, which may include layers of insulating, semiconducting, and conducting layers or features formed thereon, used to manufacture microelectronic devices. For example, the method and apparatus of the present invention may be employed to form copper conductive features by polishing copper metal deposited onto low-k material such as porous silica.

Exemplary polishing system 102 includes four polishing stations 108, 110, 112, and 114, which each operate independently; a buff station 116; a transition stage 118; a robot 120; and optionally, a metrology station 122. Polishing stations 108-114 may be configured as desired to perform specific functions; however, in accordance with the present invention, at least one of stations 108-114 includes an orbital polishing mechanism configured to remove low-k material or conductive material overlying low-k material as described herein. The remaining polishing stations may be configured for chemical mechanical polishing of the same or other materials, electrochemical polishing, electrochemical deposition, or the like.

Polishing system 102 also includes polishing surface conditioners 140, 142. The configuration of conditioners 140, 142 generally depends on the type of polishing surface to be conditioned. For example, when the polishing surface comprises a polyurethane polishing pad, conditioners 140, 142 suitably include a rigid substrate coated with diamond material. Various other surface conditioners may also be used in accordance with the present invention.

Clean system 104 is generally configured to remove debris such as slurry residue and material (e.g., copper metal) removed from the wafer surface during polishing. In accordance with the illustrated embodiment, system 104 includes clean stations 124 and 126, a spin rinse dryer 128, and a robot 130 configured to transport the wafer between clean stations 124, 126 and spin rinse dryer 128. In accordance with one aspect of this embodiment, each clean station 124 and 126 includes two concentric circular brushes, which contact the top and bottom surfaces of a wafer during a clean process.

Figure 2 illustrates a clean station (e.g., station 124) in greater detail. Clean station 124 includes brushes 202, 204 mounted to brush platens 206, 208. Station 124 also includes rollers—e.g., capstan rollers 210, 212 to keep the wafer in place during the clean process.

In accordance with one embodiment of the invention, during the clean operation, a wafer is placed onto the capstan rollers, and lower clean platen 208 and brush 204 rise to contact and apply pressure to a lower surface of the wafer, while upper platen 206 and brush 202 lower to contact the upper surface of the wafer The brushes are then caused to rotate about their axes to scour the surfaces of the wafer in the presence of a fluid such as deionized water or a NH_4OH solution.

Wafer load and unload station 106 is configured to receive dry wafers for processing in cassettes 132. In accordance with the present invention, the wafers are dry when loaded onto station 106 and are dry before return to station 106.

In accordance with an alternate embodiment of the invention, clean system 104 may be separate from the polishing apparatus. In this case, load station 106 is configured to receive dry wafers for processing, and the wafers are held in a wet (e.g., deionized water) environment until the wafers are transferred to the clean station.

In operation, cassettes 132, including one or more wafers, are loaded onto apparatus 100 at station 106. A wafer from one of cassettes 132 is transported to a stage 134 using a dry robot 136. A wet robot 138 retrieves the wafer at stage 134 and transports the wafer to metrology station 122 for film characterization or to stage 118 within polishing system 102. In this context, a "wet robot" means automation equipment configured to transport wafers that have been exposed to a liquid or that may have liquid remaining on the wafer and a "dry robot" means automation equipment configured to transport wafers that are substantially dry. Robot 120 picks up the wafer from metrology station 122 or stage 118 and transports the wafer to one of polishing stations 108-114 for chemical mechanical polishing in accordance with the present invention.

After polishing, the wafer is transferred to buff station 116 to further polish the surface of the wafer. The wafer is then transferred to stage 118, which keeps the wafers in a wet environment, for pickup by robot 138. Once the wafer is removed from the polishing surface, conditioners 140,142 may be employed to condition the polishing surface. Conditioners 140, 142 may also be employed prior to polishing a wafer to prepare the surface for wafer polishing.

After a wafer is placed in stage 118, robot 138 picks up the wafer and transports the wafer to clean system 104. In particular, robot 138 transports the wafer to robot 130, which in turn places the wafer in one of clean stations 124, 126. The wafer is cleaned using one or more stations 124, 126 and is then transported to spin rinse dryer 128 to rinse and dry the wafer prior to transporting the wafer to load/unload station 106 using robot 136.

Figure 3 illustrates a top cut-away view of another exemplary polishing apparatus 300, suitable for removing friable or brittle material such as low-k material or conductive material deposited thereon from a wafer surface. Apparatus 300 is suitably coupled to carousel 400, illustrated in Figure 4, to form an automated chemical mechanical polishing system. A chemical

mechanical polishing system in accordance with this embodiment may also include a removable cover (not illustrated in the figures) overlying apparatus 300 and 400.

Apparatus 300 includes three polishing stations 302, 304, and 306, a wafer transfer station 308, a center rotational post 310, which is coupled to carousel 400, and which operatively engages carousel 400 to cause carousel 400 to rotate, a load and unload station 312, and a robot 314. Furthermore, apparatus 300 may include one or more rinse washing stations 316 to rinse and/or wash a surface of a wafer before or after a polishing process and one or more pad conditioners 318. Although illustrated with three polishing stations, apparatus 300 may include any desired number of polishing stations and one or more of such polishing stations may be used to buff a surface of a wafer as described herein. Furthermore, although illustrated without an integrated clean system, apparatus 300 may include a wafer clean and dry system similar to clean system 104 described above.

Wafer transfer station 308 is generally configured to stage wafers before or between polishing and/or buff operations and may be further configured to wash and/or maintain the wafers in a wet environment.

Carousel apparatus 400 includes polishing heads 402, 404, 406, and 408, each configured to hold a single wafer and urge the wafer against a polishing surface (e.g., a polishing surface associated with one of stations 302-306). Each carrier 402-408 is suitably spaced from post 310, such that each carrier aligns with a polishing station or station 408. In accordance with one embodiment of the invention, each carrier 402-408 is attached to a rotatable drive mechanism using a gimbal system (not illustrated), which allows carriers 402-408 to cause a wafer to rotate (e.g., during a polishing process). In addition, the carriers may be attached to a carrier motor assembly that is configured to cause the carriers to translate—e.g., along tracks 410 and 412 or radially along a track 414. In accordance with one aspect of this embodiment, each carrier 402-408 rotates and translates independently of the other carriers. In accordance with another embodiment, carriers 402-408 are configured to orbit about an axis. Such orbital motion may be in lieu of or in addition to any rotational or linear motion.

In operation, wafers are processed using apparatus 300 and 400 by loading a wafer onto station 308, from station 312, using robot 314. When a desired number of wafers are loaded onto the carriers, at least one of the wafers is placed in contact with a polishing surface. The wafer may be positioned by lowering a carrier to place the wafer surface in contact with the polishing

surface or a portion of the carrier (e.g., a wafer holding surface) may be lowered to position the wafer in contact with the polishing surface.

Figure 5 illustrates an apparatus 500, suitable for use in connection with a polishing station (e.g., one or more of polishing stations 108-114, 302-306), in accordance with various embodiments of the present invention. Systems such as apparatus 100 and 300 may include one or more polishing apparatus 500 combined with other forms of polishing apparatus such as linear, rotational, or web index style polishers. Apparatus 500 may also include a temperature control mechanism, including a chiller 520, to regulate the temperature of the polishing solution.

Apparatus 500 includes a lower polish module 502, including a platen 504 and a polishing surface 506 and an upper polish module 508, including a body 510 and a retaining ring 512, which retains the wafer during polishing. In accordance with the present invention, polishing surface 506 includes a material conducive to removal of material such as copper, which is deposited over low-k material such as porous silica material. Such polishing materials include polyurethane polishing pads such as IC 1000 pads available of Rodel, Inc. of Phoenix, Arizona, nylon/polyurethane pads, or polyester pads. Suitable slurry materials for use in connection with such polishing surfaces include fumed or colloidal silica slurries, acid slurries, alumina slurries, reactive liquid systems, and the like.

Upper polish module or carrier 508 is generally configured to receive a wafer for polishing and urge the wafer against the polishing surface during a polishing process. In accordance with one embodiment of the invention, carrier 508 is configured to receive a wafer, apply a vacuum force (e.g., about 55 to about 70 cm Hg at sea level) to the backside of wafer 516 to retain the wafer, move in the direction of the polishing surface to place the wafer in contact with polishing surface 506, release the vacuum, and apply a force (e.g., about 0 to about 8 psi., and preferably about 0.25 to about 2 psi.) in the direction of the polishing surface. In addition, carrier 508 is configured to cause the wafer to move. For example, carrier 508 may be configured to cause the wafer to move in a rotational, orbital, or translational direction. In accordance with one aspect of this embodiment, carrier 508 is configured to rotate at about 2 rpm to about 20 rpm about an axis 520.

Carrier 508 may also include a resilient film 514 interposed between a wafer 516 and body 510 to provide a cushion for wafer 516 during a polishing process. Carrier 508 may further include an air bladder 518 configured to provide a desired, controllable pressure to a backside of

the wafer during a polishing process. In this case, the bladder may be divided into zones such that various amounts of pressure may be independently applied to each zone. A carrier including multiple pressure zones, which is suitable for use in connection with the present invention, is disclosed in Application Serial Number 09/540,476, by the assignee hereof, the content of which is hereby incorporated by reference.

Lower polishing module 502 is generally configured to cause the polishing surface to move. By way of example, lower module 502 may be configured to cause the polishing surface to rotate, translate, orbit, or any combination thereof. In accordance with one embodiment of the invention, lower module 502 is configured such that platen 504 orbits with an orbital radius of about 0.25 to 1 inch, about an axis 522 at about 500 to about 200, and preferably about 1000 revolutions per minute, while simultaneously causing the platen 504 to dither or partially rotate, such that the relative velocity between the wafer surface and the polishing surface is about 0.5 to about 3.2 meters/second. An orbital polishing module is describe in greater detail in United States Patent No. 5,554,064, issued to Breivogel et al., the content of which is incorporated herein by reference.

In accordance with an alternate embodiment of the invention, material may be removed by orbiting a wafer carrier about an axis as discussed above in connection with orbiting the platen, while rotating the platen at a relatively low speed or maintaining the platen in a stationary position, such that the relative velocity between the wafer surface and the polishing surface is about 0.8 to about 3.2 meters per second.

Because low-k materials are relatively brittle, a polishing process in accordance with the present invention is configured to reduce friction and therefore shear forces applied to the low-k material during a polishing operation (e.g., during a conductive material removal process). For example, the orbital speed of lower polish module 502 is increased compared to conventional polishing operations to decrease the friction and shear force applied to the surface of the wafer. In addition, the down force applied to the wafer from upper polish module 508 is reduced to further reduce the friction and shear forces.

Figure 6 illustrates a portion of a lower polishing module 600, including a platen 602 and a polishing surface 604, in accordance with one embodiment of the invention. Platen 602 and polishing surface 604 include channels 606 and 608 formed therein to allow polishing fluid such as slurry to flow through platen 602 and surface 604 toward a surface of the wafer during the

polishing process. Flowing slurry toward the surface of the wafer during the polishing process is advantageous because the slurry acts as a lubricant and thus further reduces friction between the wafer surface and polishing surface 604. The slurry flow rates may be selected for a particular application; however, in accordance with one embodiment of the invention, the slurry flow rates are less than about 200 ml/minute and preferably about 120 ml/minute.

Figures 7A and 7B illustrate a portion of a lower polish module 700 in accordance with yet another embodiment of the invention. Structure or polish head 700 includes a fluid channel 702 to allow heat exchange fluid such as ethylene glycol and/or water to flow therethrough to cool a surface of a polishing surface 704 such as a polishing pad. Module 700 is suitably formed of material having a high thermal conduction coefficient to facilitate control of the processing temperature.

Lower polish head 700 includes a top plate 706, a channel plate 708, and a base plate or bell housing 710, which are coupled together to form polish head 700. Top plate 706 includes a substantially planar top surface to which a polishing surface 704 such as a polishing pad is attached—e.g., using a suitable adhesive. Channel section 708 includes channel 702 to allow heat exchange fluid to flow through a portion of polish head 700. Bottom section 710 is configured for attachment of the polish head to a platen shaft. To allow slurry circulation through polish head 700, cover plate 706, channel section 708, and bottom plate 710 each include channels 712 similar to channels 606 and 608, illustrate in Figure 6, through which a polishing solution may flow. In accordance with one exemplary embodiment of the invention, top plate 708 is brazed to channel section 708 and the combination of top plate 706 and channel plate 708 is coupled to lower plate 710 using clamp ring 726, or alternatively another suitable attachment mechanism such as bolts.

Heat exchange fluid is delivered to polish head 700 through a fluid delivery conduit 714 and a flexible fluid delivery tube 716. Fluid circulates through channel 702 and exits at outlet 730.

Slurry is distributed to polish head 700 using a flexible slurry delivery tube 722 and a slurry delivery conduit 720 to deliver the slurry to a slurry chamber 719. Slurry is then distributed to a top surface of polish head 700 using conduits 712. In accordance with one aspect of this embodiment, slurry chamber 719 is formed by securing a slurry manifold cover 718 to a lower surface of channel section 708.

In an alternative embodiment, the channel groove is formed in the underside of the cover plate. The channel groove may be sealed by attaching a circular disk having a planar top surface to the underside of the cover plate. The bottom section is attached to the circular disk, or, alternatively, the junction of the circular disk and the bottom section could be combined. In either this method or the illustrated method, a channel groove through which a heat exchange fluid can be circulated is formed beneath the substantially planar surface of the platen assembly.

In accordance with yet another embodiment of the invention, the temperature of the polishing process may be controlled by providing a heat exchange fluid to the backside of wafer 212. Apparatus for exposing a heat exchange fluid to the backside of a wafer are well known in the art. For an example of an apparatus configured to regulate the polishing rate of a wafer by backside heat exchange, see U.S. Patent No. 5,605,488, issued to Ohashi et al. on February 25, 1997, which patent is hereby incorporated by reference.

Figure 8 illustrates a top view of polishing surface 802 in accordance with the present invention. As illustrated in both Figures 6 and 7, and in accordance with an exemplary embodiment of the invention, polishing surface 802 includes apertures 804 extending through surface 802. Apertures 804 are suitably aligned with channels formed within platen 600, such that polishing solution may circulate through platen 602 and polishing surface 802 as described above in connection with Figures 6, 7A, and 7B. Surface 800 also includes grooves 806. Grooves 806 are configured to effect transportation of the polishing solution on polishing surface 802 during a polishing process. Polishing surface 802 may also be porous, further facilitating transportation of the polishing solution. It will be appreciated that polishing surface 802 may have any suitably-shaped openings that are configured to produce a uniform or other desired slurry distribution across the surface. For example, grooves 806 may be configured to facilitate a hydroplaning action such that a wafer floats on polishing solution during a polishing process. In accordance with one exemplary embodiment of the invention, surface 802 is formed of polyurethane, having a thickness of about 0.050 to about 0.080 inches, and grooves 806 are formed using a gang saw, such that the grooves are about 0.015 to about 0.045 inches deep, with a pitch of about 0.2 inches and a width of about 0.15 to about 0.30 inches.

Although the present invention is set forth herein in the context of the appended drawing figures, it should be appreciated that the invention is not limited to the specific form shown. For example, although the method and apparatus are described in connection with polishing copper

deposited onto low-k material, the inventive method and apparatus may be used to polish other materials deposited onto friable material and/or to polish the friable material. Various other modifications, variations, and enhancements in the design and arrangement of the chemical mechanical polishing methods and apparatus as set forth herein may be made without departing from the spirit and scope of the present invention as set forth in the appended claims.